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Request for grant of a patent

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1. Your reference	HL71321/000/CIV
2. Patent application number *(The Patent Office will fill in this part)*	9907407.2 01APR99 E436928-1 D02847 P01/7700 0.00 - 9907407.2
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	University of Bristol Senate House Tyndall Avenue Bristol BS8 1TR UK
Patents ADP number *(If you know it)* If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom 7981810C01
4. Title of the invention	
5. Full name of your agent *(If you have one)*	Haseltine Lake & Co.
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Imperial House 15-19 Kingsway London WC2B 6UD
Patents ADP number *(If you know it)*	34001 ✓

	Country	Priority application number *(if you know it)*	Date of filing *(day/month/year)*
6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number			

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Description	12
Claim(s)	3 8
Abstract	~~1~~ –
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Priority documents	0
Translations of priority documents	0
Statement of inventorship and right to a grant of patent *(Patents Form 7/77*	0
Request for preliminary examination and search *Patents Form 9/77)*	~~1~~ –
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Any other documents *(please specify*	-

11. I/We request the grant of a patent on the basis of this application

Signature Haseltine Lake   Date ~~31st~~ March 1999

12. Name and daytime telephone number of person to contact in the United Kingdom   David C. O'Connell   [0117] 9103200

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AN OPTICAL CROSSPOINT SWITCH USING VERTICALLY COUPLED WAVEGUIDE STRUCTURE

An optical crosspoint switch structure is disclosed. The switch permits light signals to be diverted from any of arbitrary number of input ports to any or several of an arbitrary number of output ports. The switch consists of two groups of intercepting optical waveguides formed on a planar substrate, which are the input and output waveguides respectively. At each intersection, another waveguide is formed above the input and output waveguides. Optical coupling between this upper waveguide and the input/output waveguides is controlled by an electrical or optical signal. The upper waveguide has an corner mirror at the intersection. When the control signal allows, light couples from the input waveguide to the upper waveguide. After being reflected by the corner mirror, the light couples from the upper waveguide into the output waveguide. The upper waveguide incorporates the active switching element, allowing high modulation depth and low crosstalk level.

FIELD OF INVENTION

The present invention relates to optical components and in particular to an optical crosspoint switch array structure.

DESCRIPTION OF THE RELATED ART

An optical crosspoint switch array is used in an optical communications system/network to route light signals. It allows light to be diverted from (1) any one of input ports to any one or more output ports (routing), (2) several input ports to an equal or lower number of output ports in an arbitrary order (shuffling or combination), and , (3)any one input port to several output ports (broadcasting). The switch can have an arbitrary number of input and output ports and is designed to be readily scaleable. The realisation of these functions important applications in an optical communications network.

Three main kinds of conventional structures for optical crosspoint switches have been proposed. The first kind splits all optical inputs into a number of branches, as described by Kato, T., et al, in IEICE Trans. on Electronics, Vol.E82C, No.2 pp.305-312, 1999. The number of branches equals the number of outputs. Then it seeks to regroup and recombine these branches. Switching is performed by blocking these branches before recombination. The second kind uses two groups of perpendicular waveguides on a planar substrate as inputs and outputs, respectively. Switching is achieved by constructing couplers in the same plane, as described by Fish, G. A., et al, IEEE Photonics Technology Letters, Vol.10, No.2, pp.230-232, 1998. The third kind also uses two groups of perpendicular waveguides on a planar substrate as inputs and outputs, respectively. Switching is achieved by constructing directional couplers in the vertical direction using only refractive index change as the switching mechanism, as described in 'analysis of an InGaAsP/InP twin-overlayed-waveguide switch' by R. Maciejko, A. Champagne, B. Reid, and H Mani, in IEEE Journal of Quantum Electronics, 1994, Vol.30, No.9, pp.2106-2113.

However, the first kind of structure has the disadvantages that it has a high insertion loss proportional to the number of outputs and that it uses large substrate area. The second kind of structure has the disadvantages that it uses large substrate area. The third structure has the disadvantage that high modulation depths and low crosstalk levels are difficult to achieve.

Summary of the Invention

The object the present invention is to provide an optical crosspoint switch scheme employing vertical optical coupling with high modulation depth and minimum crosstalk levels between channels.

Another object of the present invention is to provide an optical crosspoint switch occupying a small area per crosspoint (input/output pair).

Still, another object of the present invention is to provide, but not limited to, one particular embodiment of the scheme, which utilises simultaneous refractive index and optical gain changes in the upper waveguide.

Still, another object of the present invention is to make po , but not to limit to, another particular embodiment of the scheme, which utilises simultaneous refractive index and optical absorption changes in the waveguide coupler.

To achieve the object of the invention, as embodied and broadly described herein and illustrated in Fig.1, two groups of intercepting waveguides, namely the input(01) and the output(02) waveguides, are formed on a planar substrate of an appropriate material. Near each crosspoint, another layer of waveguide is formed above the input and output waveguides, forming a vertically coupled waveguide structure [VCWS(03)]. Vertical optical coupling between this upper waveguide and the lower input/output waveguides is controlled by an electric or optical signal. The upper waveguide has total internal reflection [TIR(04)] corner mirror at the crosspoint. When the control signal selects one particular switch, light couples from the input waveguide to the upper waveguide fully or partially. Reflected by the corner mirror, the light is steered by an angle, then couples from the upper waveguide into the output waveguide. High modulation depth and low crosstalk level are achieved by changing the optical absorption and/or gain in the waveguides synchronously with the switching action.

To achieve another object of the invention, the thickness and the refractive index of the lower layer, the upper waveguide layer and the spacing layer between them are designed so that the coupling length is reduced to the extent that the distance between adjacent ports is decided by the space needed for the input/output optical fibre coupling.

To achieve one particular embodiment of the invention, the lower waveguide, the spacing layer and the upper waveguide layer are consequently formed on a semiconductor substrate suitable for the signal wavelength, to produce a wafer. The bandgap of the lower waveguide is such that it is transparent at the signal wavelength. The bandgap of the upper waveguide is such that it provides high optical absorption when there is no carrier injection, and provides optical gain when there is carrier injection. The propagation constants of the two waveguides are so designed that, when there is no carrier injection, the lower waveguide has smaller propagation constant that the upper waveguide. The doping profile of the layers ensures that most injected carriers are confined in the upper waveguide.

To achieve another particular embodiment of the invention, the lower waveguide, the spacing layer and the upper waveguide layer are consequently formed on a III-V

semiconductor substrate suitable for the signal wavelength, to produce a wafer. The bandgap of the lower waveguide is such that it is of low optical loss at the signal wavelength. The bandgap of the upper waveguide is such that it provides high optical absorption when there is applied electric field, and is of low optical loss when there is no applied electric field. The propagation constants of the two waveguides are so designed that, when there is no applied electric field, the two waveguide have equal propagation constants. The doping profile of the layers ensures that electric field will be applied mostly across the upper waveguide.

The objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learnt by practice of the invention. The objects and advantages of the invention will be realised and attained by means of the elements and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

Fig.1 illustrates the configuration of the optical crosspoint switch array with 2 inputs and 2 outputs, which can be extended to arbitrary numbers of inputs and outputs.

Figs.2A and 2B illustrate schematically propagation of the light signal at each cross point with control signal at 'on' and 'off' states, respectively. A plan (top) view and a perspective view are included in each state.

Figs.3A and 3B illustrate schematically propagation of the light signal in the first particular embodiment of the invention, with distributions of optical refractive index (n) and absorption in both 'ON' and 'OFF' states.

Figs.4A and 4B illustrate schematically propagation of the light signal in the second particular embodiment of the invention, with distributions of optical refractive index (n) and absorption in both 'ON' and 'OFF' states.

Fig. 5 shows e layer structure of a er on which the array is fabricated.

Fig. 6 shows the layout of a 4x4 switch array.

Fig. 7 illustrates a switch unit cell.

Fig. 8 shows the switching characteristics of the switch unit cell.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the preferred embodiments of the present invention, two examples of which are illustrated in accompanying drawings.

One preferred embodiment of the present invention will be explained hereinafter with references to the accompanying drawings.

At the 'ON' state, carriers are injected into, and confined in the upper waveguide of Fig.3. The upper waveguide may comprise bulk or quantum-well III-V semiconductor material such as InGaAsP, which, at the signal light wavelength, provides optical gain with adequate non-equilibrium carrier concentration but is highly absorptive when there is no such carrier concentration. The refractive index of the upper waveguide at the signal wavelength will be reduced due to the existence of these carriers, causing the reduction of the propagation constant of the upper waveguide to a value close to that of the lower waveguide. As a result, strong optical coupling happens between the two waveguides, enabling the transfer of signal from the lower input waveguide to the upper waveguide, and after reflected by the corner mirror, its transfer from the upper waveguide to the lower output waveguide. At the 'OFF' state, there is no injected carrier, the unequal propagation constant of the two waveguide layers reduce optical coupling to a weak extent. In the absence of injected carriers, high optical absorption in the upper waveguide ensures that the weak signal light that does couple into the upper waveguide is absorbed and does not couple into the output waveguide. High modulation depth and low crosstalk level is therefore achieved. This embodiment of the invention has the additional advantage of providing optical gain to compensate for the losses which may occur in the crosspoint switch or other parts of the optical transmission link.

Another preferred embodiment of the present invention will be explained hereinafter with references to the accompanying drawings.

At the 'ON' state, no electric field is applied across the upper waveguide of Fig.4. As a result, strong optical coupling happens between the two waveguides because of their equal optical propagation constants, enabling the transfer of signal from the lower input waveguide to the upper waveguide, and after reflected by the corner mirror, its transfer from the upper waveguide to the lower output waveguide. At the 'OFF' state, an electric field is applied across the upper waveguide, increasing both its refractive index

(therefore its optical propagation constant) and its absorption. The unequal propagation constant of the two waveguide layers reduce optical coupling to a weak extent. The high optical absorption in the upper waveguide ensures that the weak signal light that does couple into the upper waveguide is absorbed and does not couple into the output waveguide. High modulation depth and low crosstalk level is therefore achieved.

Other embodiments of the invention will be apparent to the skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only. with the true scope and spirit of the invention defined by the claims.

An optical crosspoint switch array combining such features as compactness, high speed, and low crosstalk level is highly desirable in high speed all-optical networks. Demonstrated devices based on various guided-wave components so far appear unable to achieve these qualities simultaneously. One kind of crosspoint switches employs MMI couplers to split all optical inputs into a number of branches.Then it seeks to regroup and recombine these branches. Switching is performed by blocking these branches before recombination. This kind of crosspoint switch has a high insertion loss proportional to the number of outputs and uses large substrate area. A second kind of switch uses two groups of perpendicular waveguides on a planar substrate as inputs and outputs, respectively. Switching is achieved by constructing directional couplers in the same plane, as described in. This also uses large substrate area. The present switch structure uses the coupling of light in the vertical direction (normal to the substrate plane, see Fig.7. to switch any input signal orthogonally to any output (Fig.8) Ultra-low crosstalk level at the `OFF' state is achieved by rendering the coupler to a weakened coupling and a high absorption state simultaneously, so that any stray signal is sufficiently attenuated. By careful .design, the couplers are made short, allowing the switch to be compact, but tolerant to fabrication variations. The component switch mechanism should allow switching on nanosecond timescales.

Device Design and Fabrication.

The crosspoint switch array presented here is fabricated on a

InGaAsP/InP wafer whose layer structure is illustrated in Fig.5 It contains two waveguide layers which are grown by MOVPE on (100) InP substrate. The undoped upper waveguide core which contains 5 unstrained 65A InGaAs quantum wells with Q1.26 barriers serves as the active layer at the wavelength of 1550nm. To control the optical coupling between the two waveguide layers, the effective refractive index of passive lower waveguide core is adjusted to a suitable value lower than that of the active waveguide by incorporating an appropriate number of quantum wells of 37A thick. The passive waveguide has a low absorption for wavelengths of 1500nm and above. Both waveguide core layers are 0.3mm thick, separated by a 1.2mm thick InP spacing layer. The spacing layer and the passive waveguide core are n-doped to $3X10^{17}/cm^3$, as well as the lower InP cladding. The design of this is such that effective switching can be achieved over the entire gain bandwidth of ~50nm of the active layer. Two perpendicular groups of ridge waveguides are formed on the wafer as input and output waveguides, respectively. The waveguides in each group are 3mm wide and 250mm apart. At present 4X4 switch arrays are fabricated (Fig.2) but it is easy to scale up to any input/output numbers. The upper active waveguide layer is removed from the waveguides except for a 200mm length extending from the intersections toward both the input and output ports, as illustrated in Fig.3. Vertical optical directional couplers are formed between these active waveguide layer and the lower passive waveguide layer. A total internal reflection mirror (TIR), the depth of which penetrates the upper waveguide, is formed diagonally cross the waveguide

ti[illegible] for the device is being tested and is believed to be in the nanosecond range determined by the carrier lifetime. Further results will be presented at the conference.

4x4 optical crosspoint switch arrays based on the first preferred embodiment and the second preferred embodiment have been designed, fabricated and tested. The devices are fabricated on InP substrate. The area of a 4x4 array is only 1.2x1.2mm, with an distance of 0.25mm between adjacent input or output waveguides. The crosstalk level at input wavelength of 1548nm is -60dB. The modulation depth (ON/OFF contrast)is 50dB. The fabrication and testing results are described in detail in the appending paper authored by the inventors.

CLAIMS:

1.A scheme of constructing an integrated optical crosspoint switch which provides minimum occupied substrate area, comprising:

forming input and output optical waveguides intersecting each other, and

forming, above the input waveguides leading to the intersection, upper waveguides into which input light can be coupled vertically in a manner controlled by an electrical or optical signal. and

providing corner mirrors at the intersections, which penetrates the upper waveguides and reflects the light in the waveguide to a perpendicular direction. and

forming, above the output waveguides leading away from the intersections, upper waveguides leading away from the corner mirror, from which light can be coupled vertically in a manner controlled by an electrical or optical signal. and

Controlling the optical mode distribution in the coupled waveguides to minimise the coupling length.

2. A design approach to minimise crosstalk level and increase the modulation depth in the crosspoint switches, comprising:

Varying the refractive index profile in the VCWS to realise switching function, and

Reducing the optical loss of, or introducing optical gain in the upper waveguide at 'ON' state to enhance the switching, and/or

Increasing the optical loss of the upper waveguide at 'OFF' state to suppress the stray signal level into the output.

3. A switch structure as claimed in claim 1, which uses the design principle claimed in claim 2.

4. A switch structure as claimed in claim 1 and 3, in which the angle between the input and output waveguides is 90 degrees.

5. A switch structure as claimed in claim 1 and 3, in which the angle between the input and output waveguides is not 90 degrees.

6. A switch structure as claimed in claim 1 3, 4 and 5, in which the refractive index of the upper waveguide is changed during switching.

7. A switch structure as claimed in claim 1 3, 4 and 5, in which the refractive index of the lower waveguide is changed during switching

8. A switch structure as claimed in claim 1 3, 4, 5, 6 and 7, in which the upper waveguide is of the same width as the lower waveguide.

9. A switch structure as claimed in claim 1 3, 4, 5, 6 and 7, in which the upper waveguide is not of the same width as the lower waveguide.

10. A switch structure as claimed in claim 1 3, 4, 5, 6, 7, 8 and 9, in which the upper waveguide is of the same thickness as the lower waveguide

11. A switch structure as claimed in claim 1 3, 4, 5, 6, 7, 8 and 9, in which the upper waveguide is not of the same thickness as the lower waveguide.

12 An array of switches, interconnected or not, consisting of individual switches which are as claimed in claim 1 3, 4, 5, 6, 7, 8, 9, 10 and 11.

13 An array of switches, as claimed in claim 12, with tapered input/output waveguide ends to enhance coupling between the array and optical fibre.

14. An individual switch or an array of switches as claimed in any of the preceding claims, wherein the substrate material is substantially planar.

15. An individual switch or an array of switches as claimed in any of the preceding claims, wherein the upper and the lower waveguides are terminated by end facets that are not perpendicular to the waveguide axis.

16. An individual switch or an array of switches as claimed in any of the preceding claims, wherein the substrate and/or waveguide material(s) are one of the following: a semiconductor, a silica-based material, a polymer.

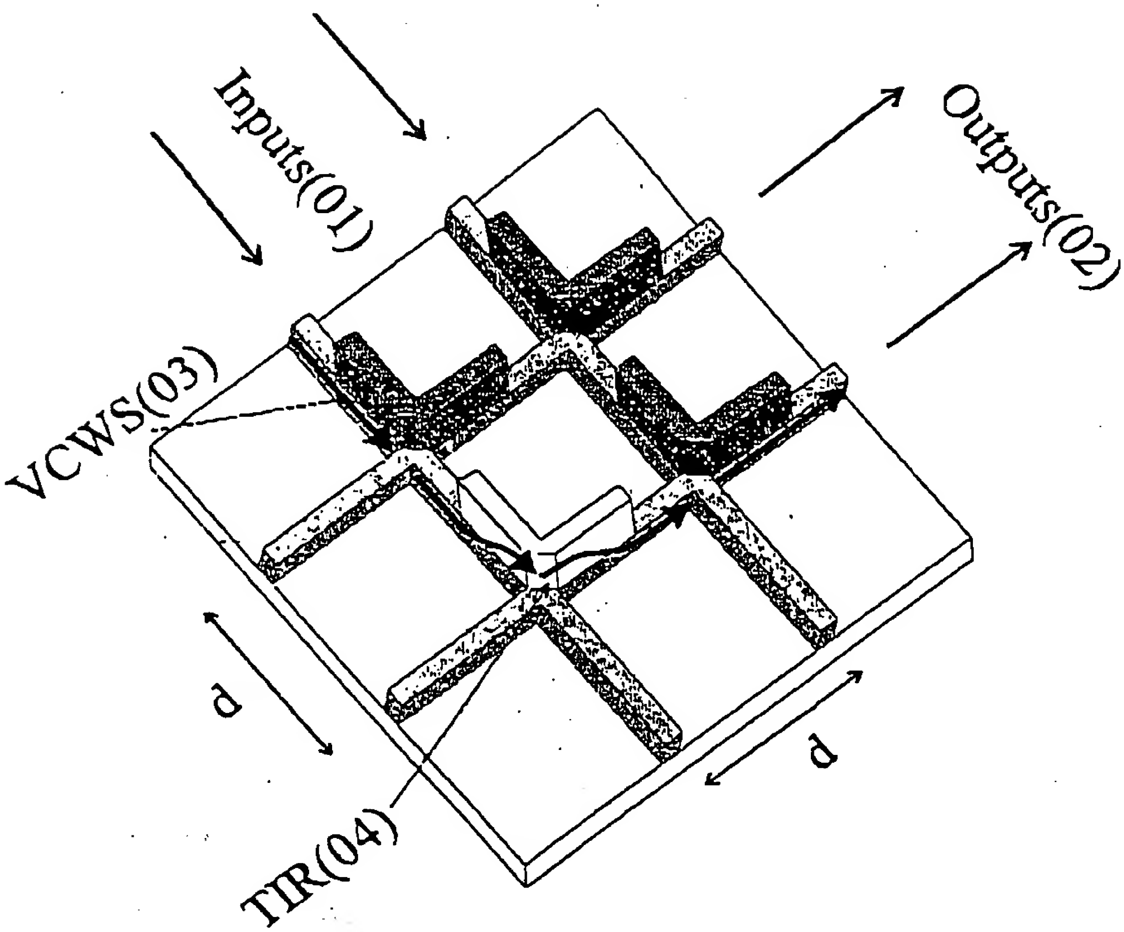
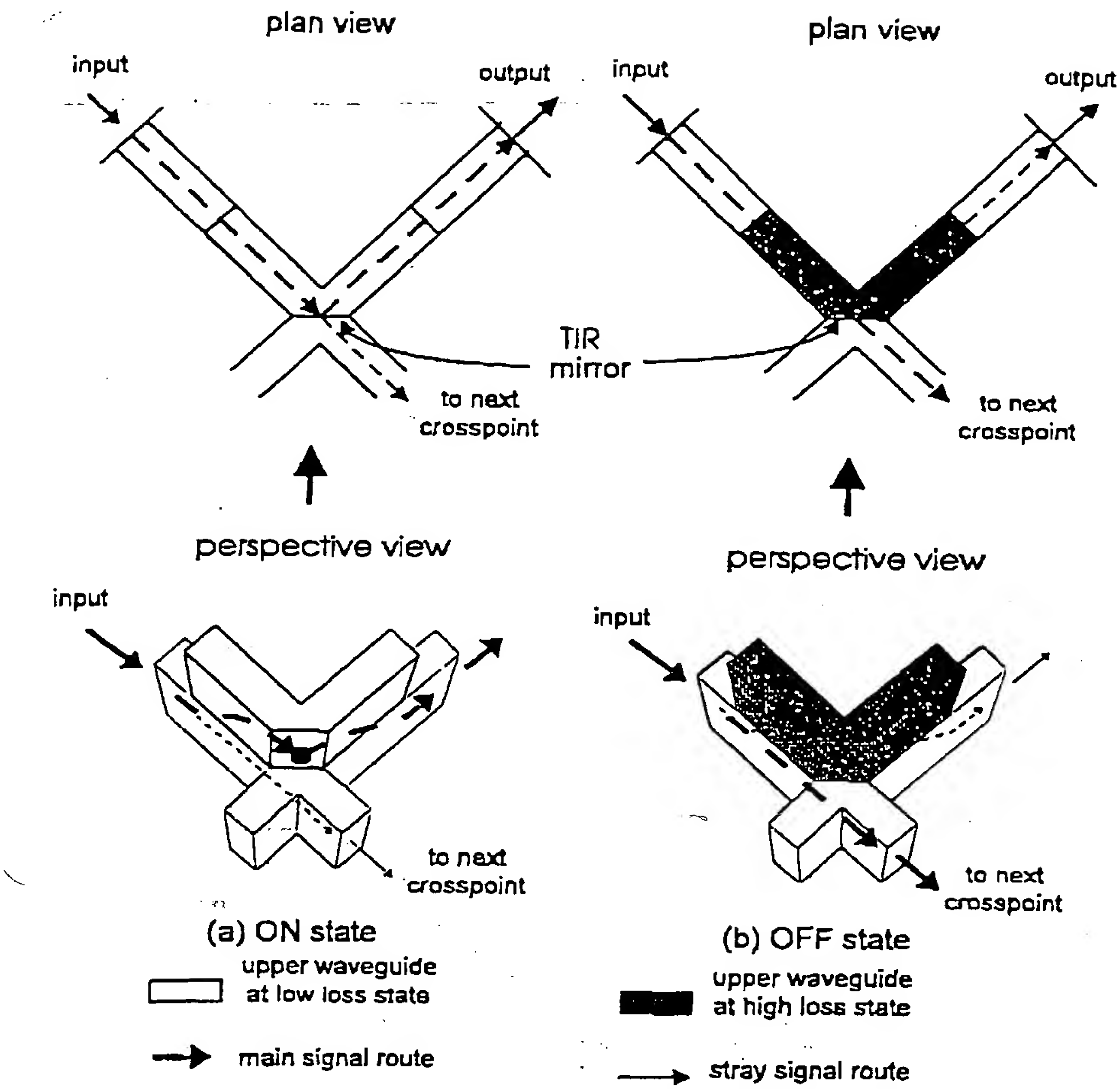


Fig.1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TIR
mirror
to next
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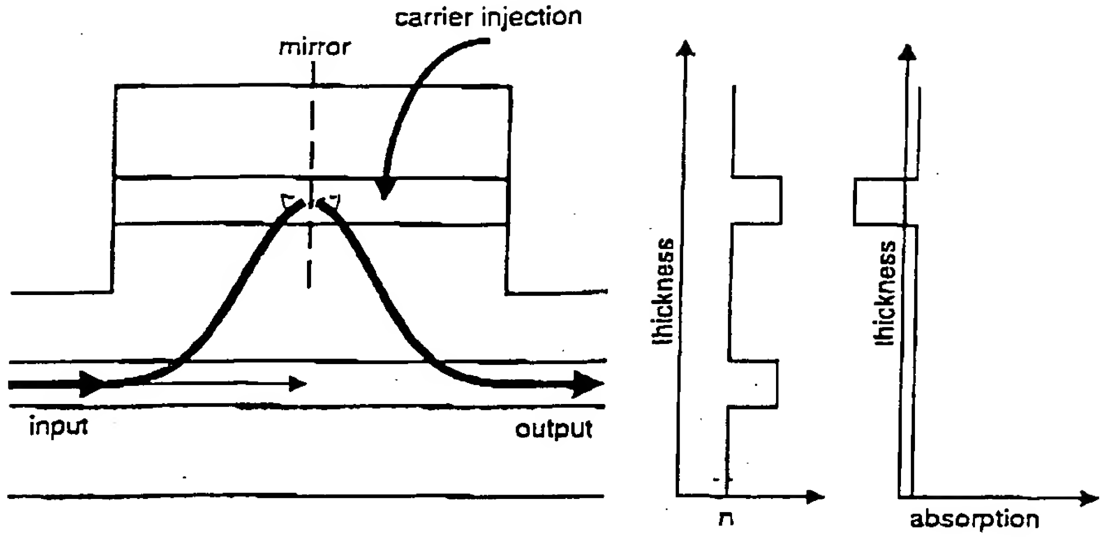
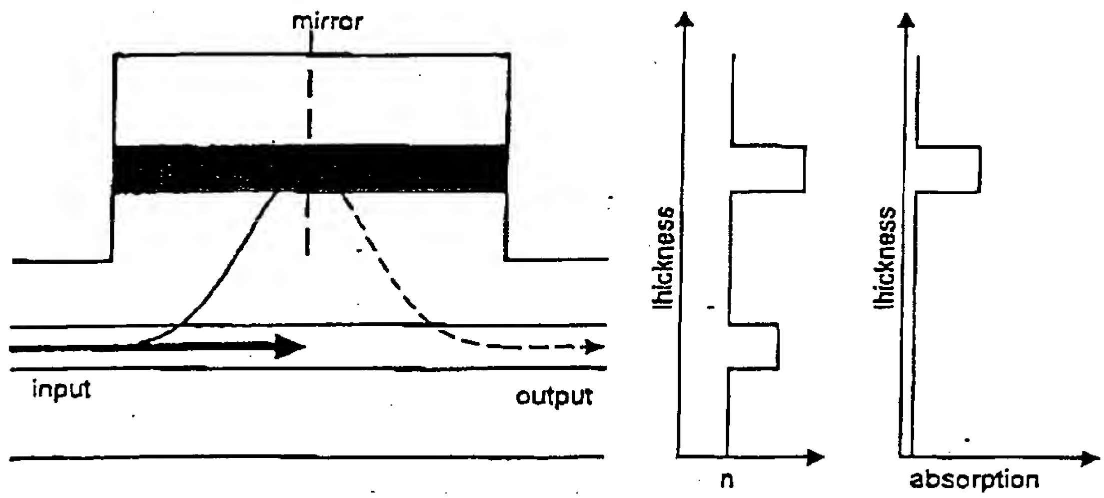
perspective view
input
input
to next
crosspoint
to next
crosspoint
(a) ON state
(b) OFF state
upper waveguide
at low loss state
upper waveguide
at high loss state
main signal route
stray signal route

Fig.2



(a) ON state



(b) OFF state

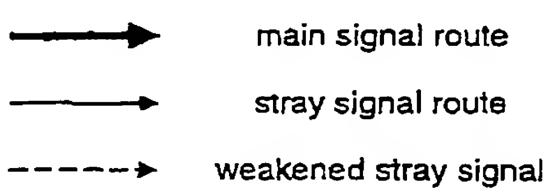
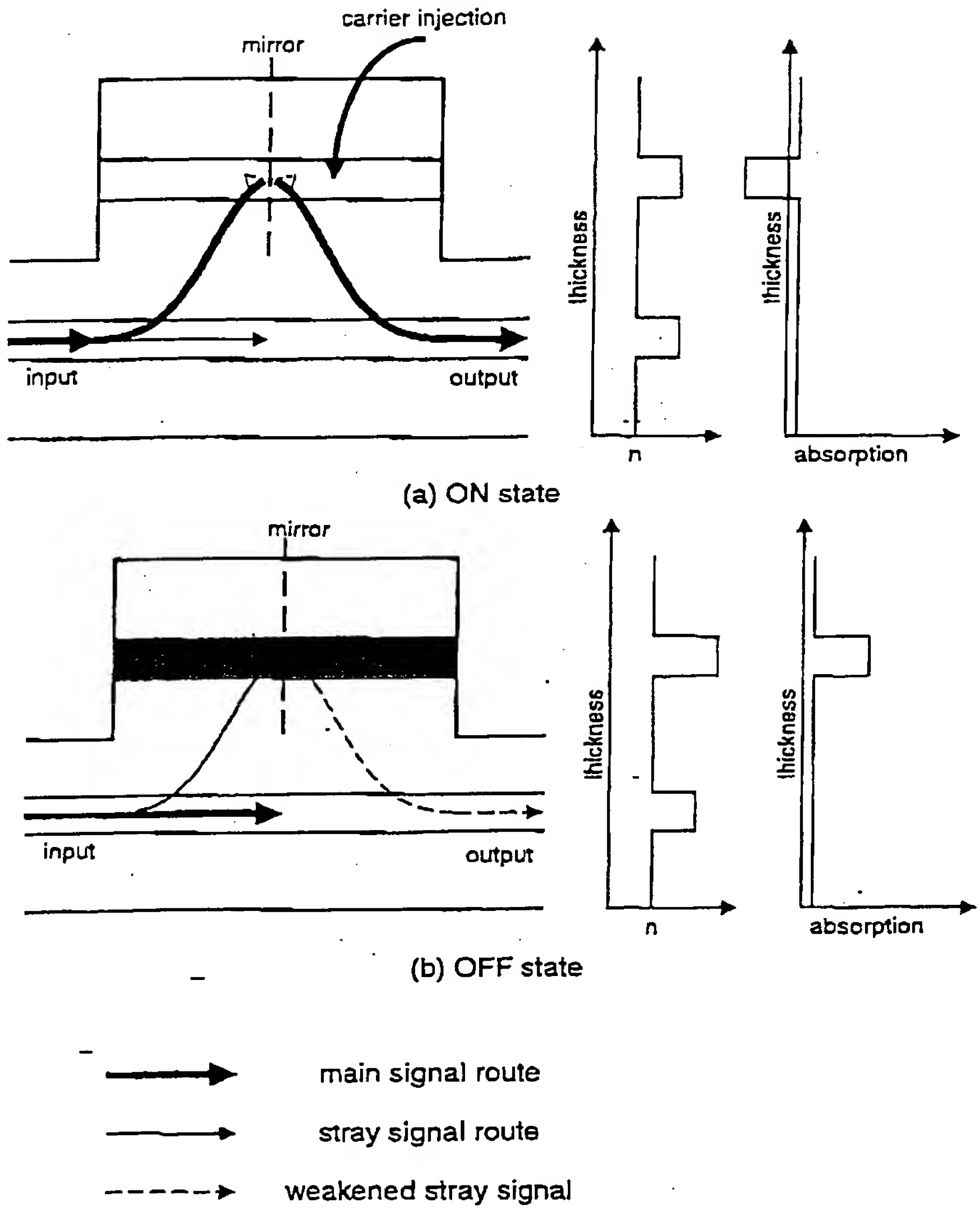


Fig.3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output
thickness
n
thickness
absorption
(a) ON state
mirror
input
output
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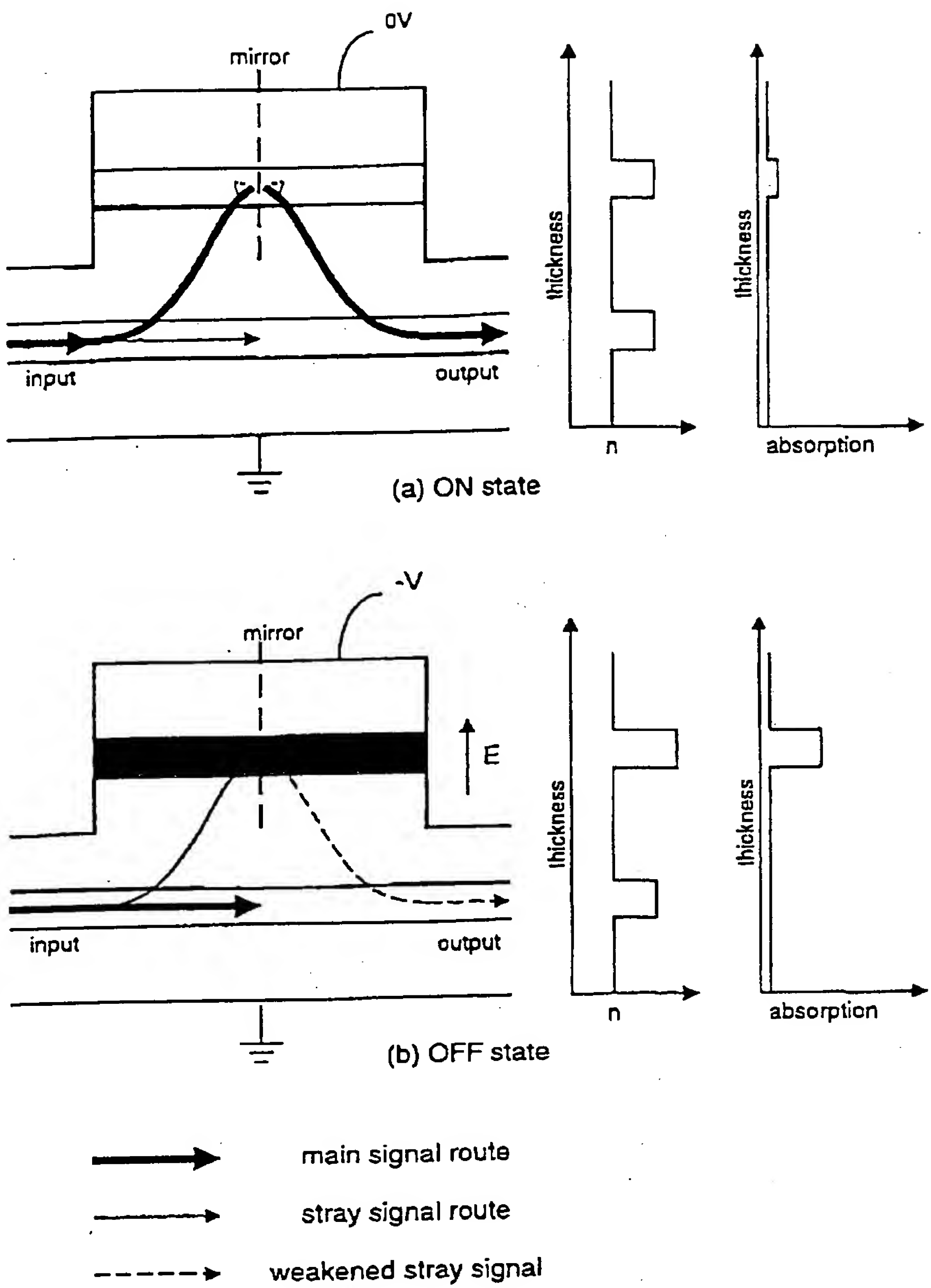
n
thickness
absorption
(b) OFF state
main signal route
stray signal route
weakened stray signal

Fig.3



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(a) ON state
-V
mirror
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thickness
n
thickness
absorption
(b) OFF state
main signal route
stray signal route
weakened stray signal

Fig. 4

FIG. 5

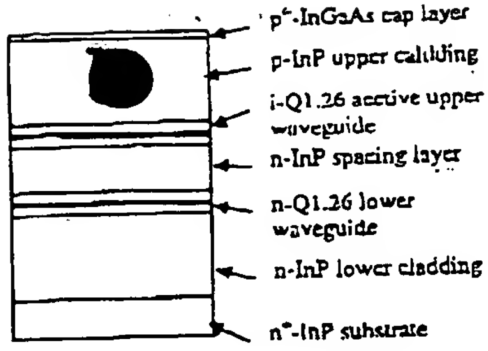


FIG. 6

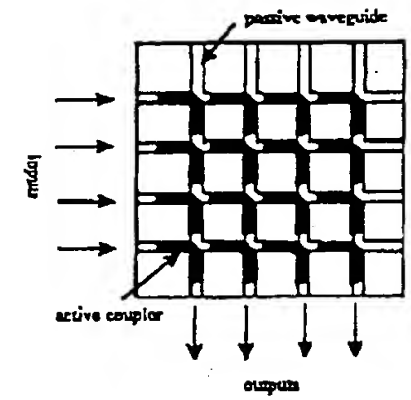


FIG. 7

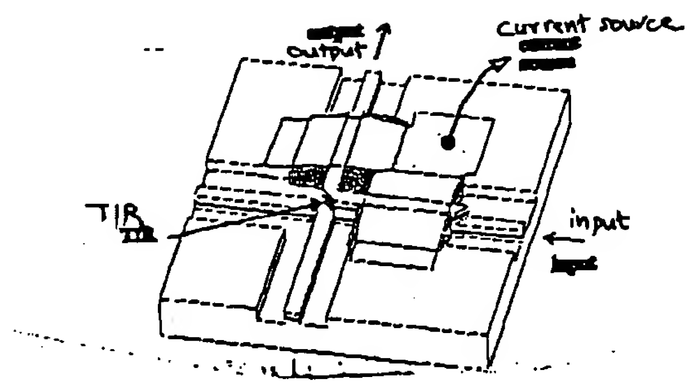
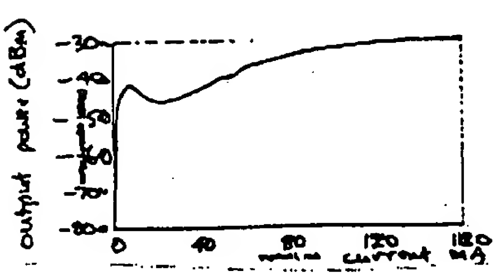


FIG. 8



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